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THE EFFECTS OF CORROSION ON THE RECOGNITION THRESHOLD OF SYMBOLS STAMPED INTO STEEL SURFACES

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RESEARCH REPORT

THE EFFECTS OF CORROSION ON THE RECOGNITION THRESHOLD OF SYMBOLS STAMPED INTO STEEL SURFACES

by

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Accomplished as Part of the
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ABSTRACT

Research Performed by Daniel Clouser
Under The Supervision of Dr. J. W. Foster

The research consisted of an experimental determination of the effects of corrosion upon the recognition thresholds of symbols stamped into unprotected steel surfaces.

This was accomplished by means of a human factors experiment designed to yield the average maximum distance at which a symbol can be recognized. Ten subjects were tested under various combinations of corrosion level, corrosion removal, and viewing angle. The resulting threshold distances were assembled in a tabular form, an analysis of variance was performed, and the results interpreted by graphical means.

The ~~more important~~ conclusions ~~drawn~~ from the experiment were: (1) even a small amount of surface corrosion is extremely detrimental to marking recognition; (2) removal of corrosion product becomes a less effective means of improving recognition characteristics of symbols as the degree of corrosion increases; and (3) viewing angle is relatively unimportant from the corrosion standpoint.

ACKNOWLEDGMENTS

Gratitude is extended to Dr. J. W. Foster for his advice and guidance during the research. The support of Dr. W. [illegible] Johnston, Dr. D. R. Shreve, and Dr. P. Hale was also appreciated.

During the course of this work, the author was employed by the U. S. Army as a career intern in the AMC Maintainability Engineering Graduate Program. He is grateful to the U. S. Army for the opportunity to participate in this program.

The ideas, concepts, and results herein presented are those of the author and do not necessarily reflect approval or acceptance by the Department of the Army.

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CHAPTER I

INTRODUCTION

Background

The objective of the following research is to investigate the effects of corrosion upon the recognition characteristics of symbols stamped into steel surfaces. The importance of such research is due mainly to the widespread use of stamped symbols in modern design. These symbols are an essential part of the design of complex equipment in that through them information pertaining to equipment maintenance is supplied to the maintenance technician. This is especially true for large organizations (e.g., Department of the Army) where the degree of the technician's familiarity with equipment is limited by the complexity and variety of equipment types. The importance of identification markings under such circumstances is emphasized in the following reference from AMCP 706-134[6]:

> "The maintenance technician's task will be more difficult, take longer and, consequently, increase the risk of error if he cannot readily identify components, parts, controls, and test points for maintenance operations."[6]

Through the use of effective identification procedures, many of the costly and time consuming consequences of poor identification characteristics can be avoided. Research into the recognition characteristics of stamped

symbols provides a basis for establishing such procedures.

Any investigation of the recognition characteristics of stamped identification markings should be primarily concerned with the properties of the markings as they exist in actual operating environments since only after equipment has been fielded do identification markings assume major importance. This is especially true for equipment that must function in hostile environments. Under such conditions, there is a high probability that the characteristics of the stamped markings will be altered during the equipment life cycle. For this reason, much more than the original effectiveness of the markings must be considered in optimizing marking effectiveness.

One possible source of change is a form of surface deterioration known as corrosion. The corrosion of steel is a very prevalent form of deterioration since it is a natural process whose sole prerequisites are water, air, and steel, all of which are common to most operating environments. Regardless of protective measures taken, when the above requirements are met, corrosion will eventually occur.

There are several ways by which surface corrosion can affect the recognition characteristics of identification stampings and, consequently, influence equipment maintainability parameters. Difficulty in trying to locate markings

can arise from the mottled, non-homogeneous appearance associated with corrosive action. This is especially true for large severely corroded parts where markings can be located over a large area and are, therefore, harder to find. In such cases, the maintenance technician is faced with the degrading and time consuming process of removing the corrosion product until the desired markings are located. A similar situation arises when markings are not legible even though their location is evident. Here again the corrosion must be removed if the desired information about the equipment is to be obtained. In this case there is also the probability that the corrosion has altered the appearance of the markings, but has not made them completely illegible. Under this condition the interpretation of the stamped symbols is open to considerable error on the part of the technician if he chooses not to spend extra time in cleaning up the metal surface.

The problems described above have a direct effect on equipment maintainability characteristics since maintenance is more difficult, takes longer, and results in an increased probability of human induced error when corrosion is present. To optimize the effectiveness of stamped identification markings it is, therefore, important to consider the possibility of corrosion. Through the use of identification criteria that take into account the de-

gree of expected corrosion, as based on operating environment, these recognition problems could be partially eliminated.

Basis of Research

In performing research into such complex processes as symbol recognition and corrosion, it soon becomes evident that tests can not be run under actual operating environments. Instead, a series of controlled observations must be set up in a closely monitored artificial situation so that the variables present in actual operating conditions can be deliberately controlled and manipulated. The research presented in the following chapters is centered around the analysis of data resulting from such a controlled experiment. This experiment is designed to determine the effects of various variables upon the recognition characteristics of symbols stamped into unprotected steel surfaces. The experiment and the consequent analysis are concerned with the effects of degree of surface corrosion, types of corrosion removal, and viewing angle.

Briefly, the remainder of this report will be structured in the following manner. Chapter II is devoted to a survey of literature in the areas associated with corrosion and visual recognition. Following this the experimental design and test apparatus are presented in Chapter

III and Chapter IV, respectively. Chapter V discusses the test procedure. In Chapter VI the methods of data analysis are described and the results of the analysis presented. Finally, Chapter VII will present the conclusions drawn from the data analysis and recommendations for the more effective use of stamped symbols.

CHAPTER II

LITERATURE SURVEY

The importance of both stamped markings and the corrosion process has long been underemphasized. As a consequence, no previous research into the interactions of corrosion and the recognition characteristics of stamped symbols was found during the literature search. The references that have been found are concerned mainly with either stamped markings, corrosion, or human visual characteristics, but not their interactions.

AMCP 706-134[6] contains recommended procedures for the identification of equipment parts within the Department of the Army. The pamphlet states that all mechanical parts that might require replacement should be marked during manufacture and then goes on to list the applicable marking criteria. For steel parts the stamping process is recommended because of its low cost and high durability.

Elements of Materials Science[8] is one of many texts providing insight into the nature of corrosion. At the time of copyright (1964) the author estimated that corrosion wasted eight to ten billion dollars per year in the United States alone. The text discusses the various corrosion reactions and the factors influencing these reactions.

For instance, corrosion is accelerated when cold-working of the metal is performed. This could prove to be an important factor in that the stamping process cold-works the metal in forming a symbol.

Another particularly valuable source of corrosion information is <u>Corrosion Testing Procedures</u>[2]. This book contains detailed descriptions of the experimental procedures employed in corrosion research. Of particular interest are two sections which pertain to the work being presented in this paper. One of these sections describes and evaluates the use of periodic salt spray as a means of corrosion inducement. Briefly, the author believes that the intermittant application of spray is a better approximation to actual service conditions than other artificial methods. Allowing the specimen to dry between successive sprayings, as would be the case in actual service, allows the accumulated corrosion product to influence the corrosion process. The other section covers the use of stamped symbols in marking specimens to be used in corrosion testing and warns of the danger of corrosion affecting the legibility of the markings. To overcome this problem, the author recommends that markings be protected as much as possible by waxing or painting, etc.

The final reference to corrosion is a description of experimental work performed by Vernon[2] in the area of urban corrosion. Although this study does not relate directly

to the research presented in this paper, it does supply insight into the complexity of the corrosion problem. Vernon's experiment investigated the effects of solids carried in suspension in urban atmospheres. One set of iron specimens was enclosed in a muslin screen that excluded suspended solids, while another set of specimens was left unprotected. The resulting much lower corrosion rate for the enclosed specimens proved the corrosion inducing nature of the solids. In further experimentation Vernon also concluded that the buildup of corrosion product on iron causes a similar increase in corrosion rate.

Human Engineering Guide to Equipment Design[7] provides a brief coverage of the functional aspects of human vision. In this reference such topics as visual acuity and brightness contrasts are discussed. Visual acuity is the measure of the size of detail that the eye can resolve. It is usually expressed as the reciprocal of the smallest visual angle at which recognition can be attained. The location of this angle and the quantities necessary for its calculation are shown in the following illustration:

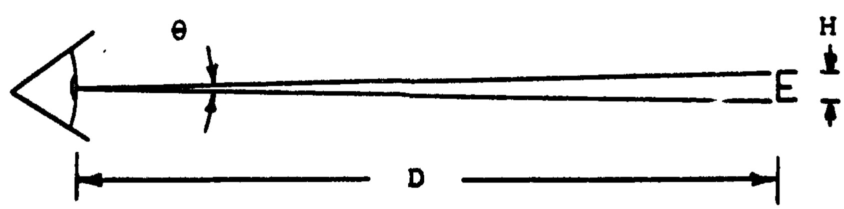

FIGURE 1 - VISUAL ANGLE DEFINITION

NOTE: Visual angle should not be confused with the viewing angle to be discussed later.

Brightness contrast is one of the main parameters influencing visual acuity. This parameter is a measure of the difference in brightness between the visual target and its background. The lower the brightness contrast the lower the visual acuity. Along the same line, the book also warns that a target displayed against a nonhomogeneous background has much poorer visual characteristics than would be predicted from threshold-acuity data.

The final reference to be discussed is concerned with the relation between illumination intensity and the readability and visibility of print with variation in brightness contrast between printing ink and paper. In this study, Tinker[4] makes the distinction between readability and visibility to take into account the complexity of the reading process. Due to learned cues involving word form of letter clusters, reading does not require complete recognition of all the letters present in a sentence. Tinker, therefore, defines the threshold of readability as a supra-threshold. As might be expected, the study concluded that the illumination requirements of readability (supra-threshold discrimination) are much less than for visibility (threshold discrimination).

To relate Tinker's work to the research presented in this paper, identification markings consist of groups of

alphamerics and numerals having no visual cues. Their recognition would be classified as threshold not supra-threshold discrimination. In other words, all the symbols comprising a marking must be recognized before recognition of the marking can be attained.

CHAPTER III

DESIGN OF EXPERIMENT

As stated previously, a carefully controlled experiment has many advantages over attempting to perform a study of corrosion and visual aspects under actual operating conditions. Through the deliberate control of experimental conditions, the influences of factors other than the experimental variables can be kept constant. In this way, the effects of corrosion on symbol recognition can be isolated and analyzed.

Independent Variables

Perhaps one of the most difficult problems encountered in experimental design is deciding which variables are to be investigated by the experiment. This is especially true for such complex processes as corrosion and visual recognition. After a careful consideration of the many factors that could possibly influence the recognition characteristics of stamped symbols, three independent variables were chosen for the experiment. Two of these variables are directly related to corrosion.

By nature, corrosion is a relatively slow process whose severity steadily increases with time. It is not surprising,therefore, that a corroded surface has charac-

teristics that depend upon the extent to which the corrosion has progressed. For this reason, the degree of surface corrosion was chosen as one of the independent variables. Through preliminary testing, four levels of corrosion were chosen by specifying the amount of time the steel surface would be exposed to a uniform corrosive action. The four levels consist of zero, three, six, and nine days in the corrosive environment to be described in the following chapter.

Another important variable pertaining to the effects of corrosion on symbol recognition is simply whether or not the corrosion product is removed before the symbols are examined. The chemical reaction responsible for corrosion produces a layer of iron oxide whose volume is much greater than that of the removed steel. The thickness of this corrosion layer increases rapidly as corrosion progresses and, consequently, should have an important influence on the recognition characteristics of symbols stamped into the steel surface. In addition to the changes resulting from corrosion buildup, however, the changes in the underlying metal surface due to corrosive action are also important, since in some cases corrosion product must be removed before symbol recognition can be attained. Corrosion destroys the clean metal appearance originally present and, consequently, might affect the visual charac-

teristics of the stamped symbols even after the corrosion product has been removed. Since the recognition characteristics of the symbols both before and after corrosion removal are important, two levels of corrosion removal were chosen. They are no removal and removal of corrosion product.

The third independent variable is the orientation of the steel surface relative to the viewer. This variable was selected to provide data on the effect of viewing angle on recognition characteristics and to determine whether any interaction exists between corrosion level and viewing angle. The viewing angle is measured as the angle between a line perpendicular to the line of sight and the metal surface. Thus if the surface is viewed directly the viewing angle is zero degrees. The two angles to be investigated in the experiment are zero and thirty degrees.

Dependent Variable

After selecting the independent variables, the next major concern was the dependent variable to be measured and evaluated through the experiment. Recognition threshold distance was chosen because it is a recognition characteristic that can be related directly to the tasks of the maintenance technician. The threshold distance for a specific set of conditions is defined in terms of the distance between the viewer's eyes and the surface being viewed

when the symbols on the surface are at the outer limit of visual recognition. Since this distance is dependent upon the visual qualities of the symbols and the surface, the recognition threshold distance can be used as a scale to compare the recognition properties of symbols under varying sets of conditions.

Unfortunately, like most other thresholds, the recognition threshold is difficult to determine directly. This is the result of the phenomenon of overshoot. Overshoot is the natural tendency of biological systems to exceed a desired goal due to an inability to precisely identify when the desired point is reached. Although overshoot causes considerable difficulty in determining visual thresholds, a simple technique can be used to overcome the problem. This is accomplished through a two-part dynamic testing procedure that cancels out the effects of overshoot and any additional effects that might result from the dynamic testing. The technique consists of first continuously decreasing the viewing distance between the viewer and the viewed surface until recognition is attained. This estimate of the recognition threshold contains overshoot error causing it to be smaller than the desired threshold. On the second trial, the viewing distance is continuously increased until the point where recognition is no longer possible. Again this distance contains overshoot, but the

overshoot is in the opposite direction from that in the first trial. By simply averaging these two distances, the overshoot is cancelled and a recognition threshold distance located.

Constant Factors

Due to time limitations, only a small proportion of those factors influencing the recognition characteristics of stamped symbols could be selected as experimental variables. The fact that certain factors were not selected, however, does not mean that they are unimportant and need not be considered in the design of the experiment. As stated at the beginning of this chapter, these factors must be controlled (held constant) if the experimental results are to be valid. The remainder of this chapter describes such factors and their values as used in the experiment.

A critical part of any visual task is illumination. The light source chosen for the experiment is an incandescent source of indirect lighting located within the visual apparatus. An internal light source ensures that the illumination of the viewed surfaces will remain constant throughout the experiment, while indirect lighting avoids the effects of visual glare. The light intensity was chosen to correspond to the illumination standard recommended by the Illuminating Engineering Society for lighting in service

garages[3]. This intensity is one-hundred footcandles.

The type, size, spacing, and depth of the stamped symbols are also recognition influencing factors. Specific values for each of these factors were selected so as to be representative of actual identification stampings while still being acceptable for experimental observation. Again, these factors were held constant during the experiment. The actual values used will be described at the beginning of the following chapter.

The composition of the steel surfaces to be examined is another factor of importance. A commonly used steel, 1018 Cold Drawn, was chosen to add to the realism of the experiment. The steel was tested without the application of protective coatings so that the corrosion properties of the steel could be observed without alteration. Research into the effects of various protective coatings would be a logical and useful extension of the research presented in this paper.

The final factor to be discussed in this section is test environment. Of necessity the test was performed in an artificial environment. This, however, does not mean that the test environment is unimportant. The test environment had to be kept constant to avoid any biasing effects of the surroundings. This was accomplished by using a single location that was relatively free from changes.

The room lighting was kept constant throughout all the trials to avoid light adaptation effects of the eye.

CHAPTER IV

EXPERIMENTAL APPARATUS

The apparatus developed for the experiment can be divided into three basic categories. These catagories are stamped marking specimens, corrosion inducing equipment, and threshold determination apparatus.

Stamped Specimens

Before the visual portion of the experiment could be performed, it was first necessary to obtain the stamped symbols for testing. Identical common steel plates - one for each degree of corrosion - were professionally stamped with symbols according to the following specifications. Each plate was stamped with a two-by-two "E" matrix (see Figure 2). The four symbols per plate were used to give a better measure of symbol recognition properties by allowing more symbols to be observed in determining the recognition threshold. The alphabetic character "E" was chosen as a representative marking because it possesses a value of relative visual acuity for perception of .85[1], which gives "E" an average perception characteristic relative to the rest of the alphabet. Each of the "E"s comprising a matrix was stamped with equal pressure into one of four orientations as chosen randomly. The four orientations, in conjunction with the ability of the "E" to be

recognized easily in the various orientations, were used to reduce error due to anticipation that might be present if all symbols were identically placed.

To ensure realism the letter size and style conform to Department of Defense recommendations; the style is Gothic capitals and the height .125 inches.[6] The plates themselves are of 1018 Cold Drawn Steel, a commonly used steel.

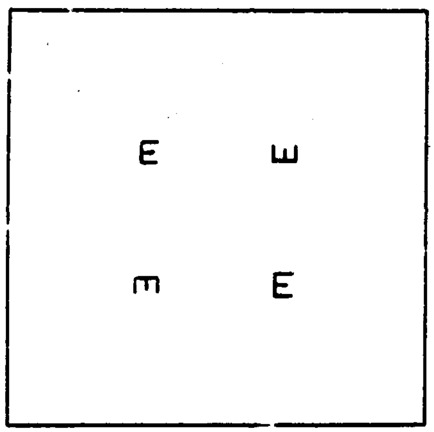

FIGURE 2 - DIAGRAM OF A STAMPED PLATE

Corrosion Inducing Equipment

The second category of experimental apparatus consists of the equipment used to induce corrosion in a con-

trolled environment. A controlled corrosive environment was chosen over a natural environment for two principle reasons. First, there is the inability to control a natural environment. Since corrosion occurs at a rate determined by the surrounding atmosphere, the severity of corrosion can be significantly altered by changes in the environment. It is necessary to set up a uniform artificial environment to ensure that the stamped plates are exposed to uniform gradients of corrosive action during their timed exposures. The second consideration is time. The time necessary for the plates to corrode to the desired levels under natural conditions could be prohibitive.

The artificial environment consisted of timed salt spray applications. This salt spray method of corrosion inducement is widely used in corrosion testing because of its simplicity and effectiveness. After being placed horizontally in a plastic tray the steel plates were sprayed at predetermined time intervals with a solution of common table salt and distilled water. A solution of one-half teaspoon of salt to one quart of water was used. This salt concentration was not chosen to correspond to any specific corrosive environment since to try to duplicate any particular natural environment would be beyond the scope of this experiment. The spraying cycle was seven sprayings per day, each two hours apart. For the remainder of the day, the plates were left untouched. When its exposure

time was completed each plate was removed from the tray and heated briefly in an oven to drive off the remaining moisture. With the moisture removed the plates could then be stored without further corrosive action.

Threshold Determination Apparatus

The final and most complex piece of experimental equipment belongs to the threshold determination category. Since there was no known existing apparatus for measuring the recognition threshold by the dynamic method discussed earlier, this equipment had to be designed and constructed. The design was based on the following requirements:

1) consistant positioning of viewed plates,
2) constant illumination,
3) a means of increasing and decreasing the distance between the viewer and the stamped plates,
4) a means of measuring the above distance, and
5) a means of changing the viewing angle.

The viewing apparatus developed consists of a plate holder and incandescent light source contained within a box with a small rectangular opening in one end to allow viewing of the plates. The plate holder, which is adjustable to the two viewing angles used in the test, ensures consistant plate positioning. The light source being located at the rear of the box provides indirect lighting of the plates. To ensure sufficient lighting to reach

the desired one-hundred foot candles and at the same time eliminate glare, the entire inside of the box is covered with crinkled aluminum foil. Through the use of a light meter, it was determined that a sixty watt bulb would supply the desired illumination level of one-hundred foot candles (see Appendix A).

The box itself is mounted on a four foot long track that allows the distance between the viewer and the plates to be increased or decreased in a continuous manner. The speed and direction of this motion is controlled by a hand crank positioned immediately underneath the center of the track (see Figure 3).

At the front of the track is an extendable arm used to position the subject during the testing. Having the subject place his forehead against the extension ensures consistant positioning of the subject. The extendable arm also increases the general capability of the visual apparatus by allowing viewing distances greater than the four feet to be investigated.

A scale that runs along one side of the track allows the experimenter to measure the viewing distance between the subject and the plate. This is the distance to be recorded during the experiment.

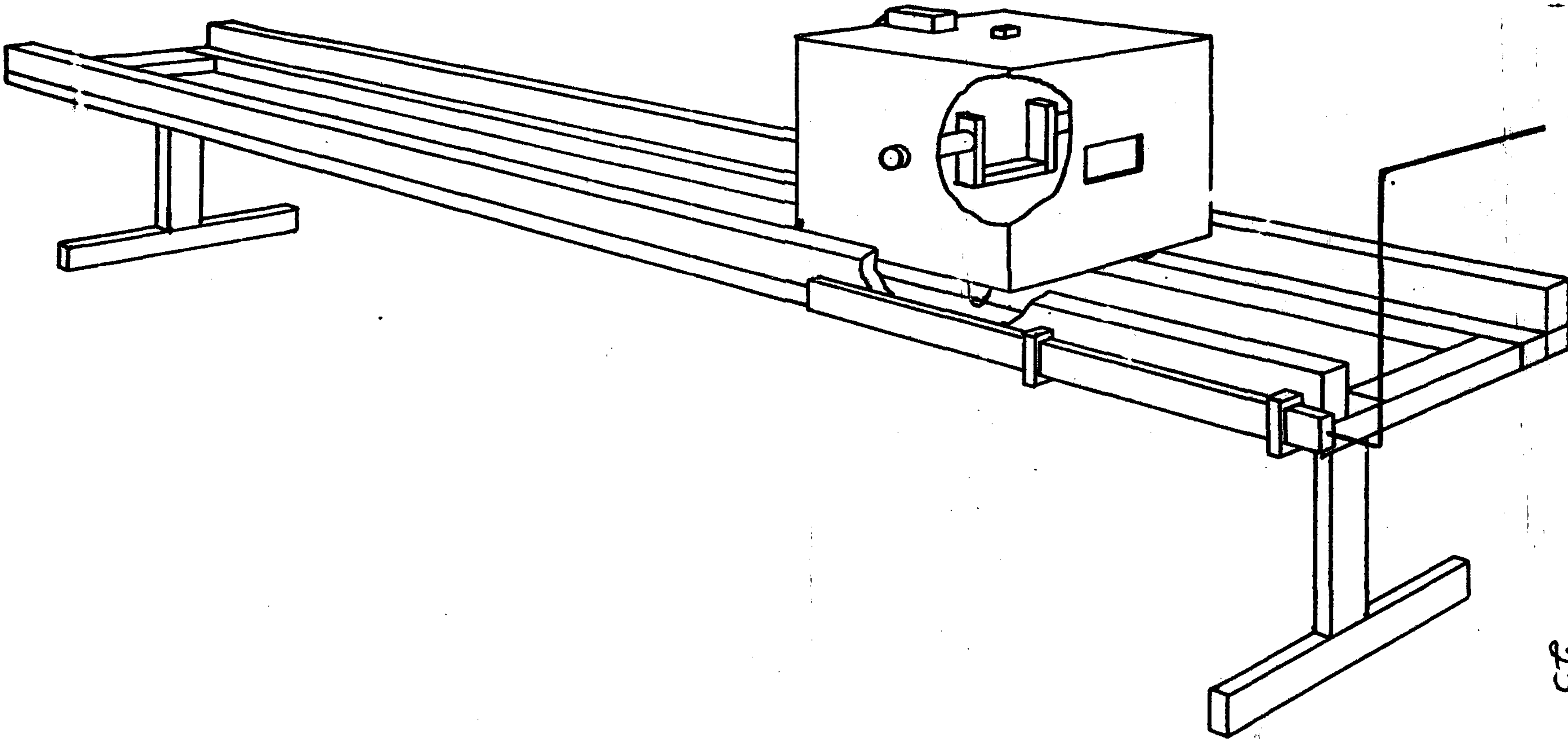

FIGURE 3 - VIEWING APPARATUS

CHAPTER V

EXPERIMENTAL PROCEDURE

Selection of Subjects

As stated earlier, the experiment was performed with each of ten subjects. These subjects were chosen from a group of graduate Industrial Engineering students. The selection of subjects from this group was advantageous in several ways. First, because of their common working location, each of the subjects was readily available. If this were not true, the results of the experiment might be biased by how much a subject was inconvenienced in being present for the test. Secondly, being graduate students themselves, the subjects realized the importance of graduate research and, consequently, worked conscientiously at the visual task presented them. Finally, the subjects selected from this group had the capability needed to adequately understand the instructions and tasks comprising the experiment. If actual maintenance technicians had been selected, the possible lack of this capability could directly influence test results.

The subjects were selected on the basis of having approximately normal vision (not requiring correction) or corrected-to-normal vision. This criteria was chosen so as not to detract from the realism of the experiment. If

only subjects with uncorrected normal vision were selected, the results would not be as applicable since all maintenance technicians do not have perfect vision. By using a cross section, it will also be possible to examine the variance in the threshold distances for subjects with varying visual capabilities.

Test Procedure

The visual recognition testing was performed in twenty separate sessions. Two sessions were required for each subject because all the subjects had to complete first a session involving the four plates with their corrosion intact before the corrosion product could be removed for the second session. To avoid any biasing effects of learning, the second session for each subject was scheduled at least one week after the first.

At the beginning of each session a standardized set of instructions (see Appendix B) was read to the subject and the operation of the apparatus demonstrated. As shown in Figure 4, the subject was then positioned with his forehead against the extendable arm of the viewing apparatus so that distance measurements could be taken.

During his first session, each subject was presented all of the combinations of the four corrosion levels, two viewing angles, and two replications in a completely randomized order. For each combination, the plate was first

moved in until the subject signaled his recognition of the required three symbols. After this distance was recorded, the plate was brought the rest of the way in and then moved away from the subject until he signaled that three of the symbols were no longer recognizable. This sequence was followed sixteen times during each session. The second session was a repeat of the first except that the surface corrosion on the plates had been removed. Again the order of testing was completely randomized.

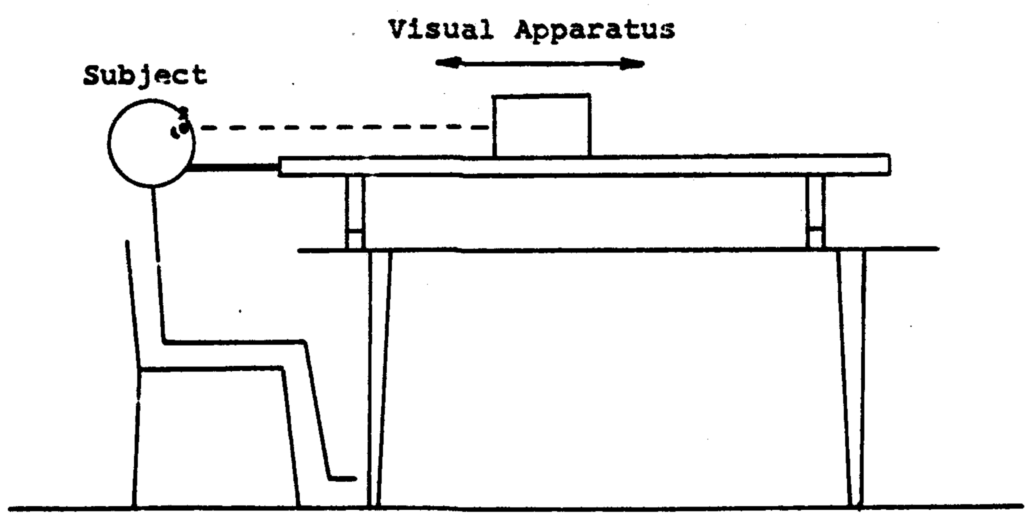

FIGURE 4 - SUBJECT POSITIONING

CHAPTER VI

ANALYSIS OF EXPERIMENTAL DATA

With the completion of data collection the analysis of the experimental data was begun. The analysis was broken up into two basic parts. The first part involved the statistical determination of which experimental variables had significant effects upon the recognition threshold of the stamped symbols. Following the determination of significance, the second part of the analysis examined the effects of the significant variables.

Analysis of Variance

Before describing the analysis of variance (ANOVA) used to determine the significances of the experimental variables, it should be recalled that the experimental variables were chosen on the basis of their probable importance to the study of the recognition characteristics of stamped symbols. As a consequence, the ANOVA should reveal that most of the variables and their interactions are significant.

The ANOVA used to investigate the significance of the three variables was a four-by-two-by-two-by-ten mixed effects factorial model with two replications per cell. This model, commonly known as the subjects-x-treatment mod-

el, was favorably used for the analysis because each subject was tested under all combinations of experimental variables and thus served as his own control.

ANOVA calculations were run partially on an IBM 1130 computer and partially by hand calculator. A computer program was written which first averaged the appropriate pairs of incoming and outgoing recognition distances to obtain the recognition thresholds for each set of conditions. The program then called an ANOVA subroutine present in the IBM scientific subroutine package, which computed the various sums of squares, degrees of freedom, and mean squares.

An EMS table was then constructed to determine the denominator to be used in calculating the F values for the variables and their interactions (see Table 1). As shown by the EMS table, the F value for any effect not containing the subject variable is calculated by dividing the mean square of that effect by the mean square of the interaction of that effect with the subject variable. For example, the F value of the CxA interaction is calculated by dividing the mean square of the CxA interaction by the mean square of the CxAxS interaction. The remainder of the effects which contain the subject variable would use the error term as the denominator in the F calculation. These effects, however, are usually not tested for significance in this

TABLE 1 - ERROR MEAN SQUARE TABLE

SOURCE	E M S
C	80 var_{C} + 8 var_{CS} + var_{E}
A	160 var_{A} + 16 var_{AS} + var_{E}
R	160 var_{R} + 16 var_{RS} + var_{E}
S	32 var_{S} + var_{E}
C x A	40 var_{CA} + 4 var_{CAS} + var_{E}
C x R	40 var_{CR} + 4 var_{CRS} + var_{E}
C x S	8 var_{CS} + var_{E}
A x R	40 var_{AR} + 8 var_{ARS} + var_{E}
A x S	16 var_{AS} + var_{E}
R x S	16 var_{RS} + var_{E}
C x A x R	20 var_{CAR} + 2 var_{CARS} + var_{E}
C x A x S	4 var_{CAS} + var_{E}
C x R x S	4 var_{CRS} + var_{E}
A x R x S	8 var_{ARS} + var_{E}
C x A x R x S	2 var_{CARS} + var_{E}
ERROR	var_{E}

type of ANOVA since differences between subjects are known to be present.

With the completion of the EMS table, the appropriate calculations were made and the ANOVA table constructed. Through comparison of the calculated F values with the tabled F statistics the significances of the experimental variables were then determined (see Table 2).

Results of ANOVA

As stated previously, the ANOVA indicates which of the experimental variables and their interactions are significant, but not the manner in which they affect the recognition threshold. For the sake of clarity, therefore, a detailed discussion of the effects of the significant variables shall be delayed until after the description of the second part of the analysis. In this section only the conclusions pertaining to significance of the effects are listed:

Experimental Variables

1) The degree of corrosion is very highly significant >> .01 level

2) corrosion removal is very highly significant >> .01 level

3) the viewing angle is not significant

Interactions

4) corrosion level x corrosion removal is very highly significant >> .01 level

TABLE 2 - ANOVA TABLE

SOURCE OF VARIATION		df	SS	MS	F
Between Corrosion Levels (C)		3	60142.86	20047.62	546.20 *
Between Viewing Angles (A)		1	115.65	115.65	3.12
Between Corrosion Removal (R)		1	29973.60	29973.60	177.40 *
Between Subjects (S)		9	5831.74	647.97	—
Interactions:	C x A	3	601.28	200.42	11.53 *
	C x R	3	14603.43	4867.81	118.85 *
	C x S	27	991.06	36.70	—
	A x R	1	76.06	76.06	13.20 *
	A x S	9	332.95	36.99	—
	R x S	9	1520.18	168.90	—
	C x A x R	3	209.12	69.70	4.10 **
	C x A x S	27	469.46	17.38	—
	A x R x S	9	51.88	5.76	—
	C x R x S	27	1082.34	40.08	—
	C x A x R x S	27	458.39	16.97	—
Within Class Error		160	1962.56	12.26	

* significant at .01 level
** significant at .05 level

C - fixed
A - fixed
R - fixed
S - random
Replications - random

5) corrosion level x viewing angle is highly significant >.01 level

6) viewing angle x corrosion removal is significant >.01 level and

7) corrosion level x corrosion removal x viewing angle is significant at .05 level.

Effects of the Significant Parameters

The second part of the analysis consisted of examining the data to determine how the experimental variables affected the recognition threshold of the stamped symbols. This was accomplished primarily by plotting values of average threshold distance versus thickness of surface corrosion for various combinations of the experimental variables, and then examining the resulting plots. The values of average threshold distances used in these plots, along with standard deviations values (see Table 3), were calculated using a short digital computer program.

Before beginning the graphical analysis of the experimental variables, the corrosive environment used in the experiment was briefly examined by means of a plot of corrosion thickness versus days within the corrosive environment. As can be seen from Figure 5, the resulting plot indicates that the rate of corrosion increased with the length of exposure. In addition to describing the corrosion product under the periodic salt spray, the graph and the accompanying tabled values also provide the basis for

TABLE 3 - TABLED AVERAGE THRESHOLD DISTANCES
(in inches)

VIEWING ANGLE 0°		DAYS OF CORROSION 0	3	6	9
CORROSION INTACT	MEAN S.D.	67.21 5.55	23.35 3.53	18.52 2.54	21.61 3.38
CORROSION REMOVED	MEAN S.D.	*	54.16 7.99	56.20 10.20	34.44 6.85

VIEWING ANGLE 30°		DAYS OF CORROSION 0	3	6	9
CORROSION INTACT	MEAN S.D.	66.06 6.72	24.53 4.38	22.25 4.26	26.56 4.03
CORROSION REMOVED	MEAN S.D.	*	52.46 8.51	53.18 8.84	41.21 8.15

* the plate without corrosion had no corrosion product to remove

the transformation from days of corrosion to thickness of corrosion product as the measure of the level of corrosion. This adds further generality to the experimental results by making the results applicable to other corrosive environments.

The second graph (Figure 6) reveals the effects of corrosion level, corrosion removal, and their interaction. As concluded from the ANOVA, all three of these effects appear to be significant. Looking first at the significance of corrosion level, it is evident that the average threshold distance has a definite decreasing trend as corrosion progresses. This is true with both the corrosion intact and removed.

Corrosion removal also produces definite effects upon the average recognition threshold. When the corrosion product is intact, there is a very sharp decrease in average threshold that occurs at the onset of corrosion. After this sharp decrease the threshold distance decreases very gradually with the build up of corrosion product. On the other hand, when the corrosion product is removed before viewing, the recognition threshold does not have this sharp initial decrease. Instead, the threshold decreases in a more linear manner.

The final effect visible in this graph is the interaction between the two variables just discussed. Although

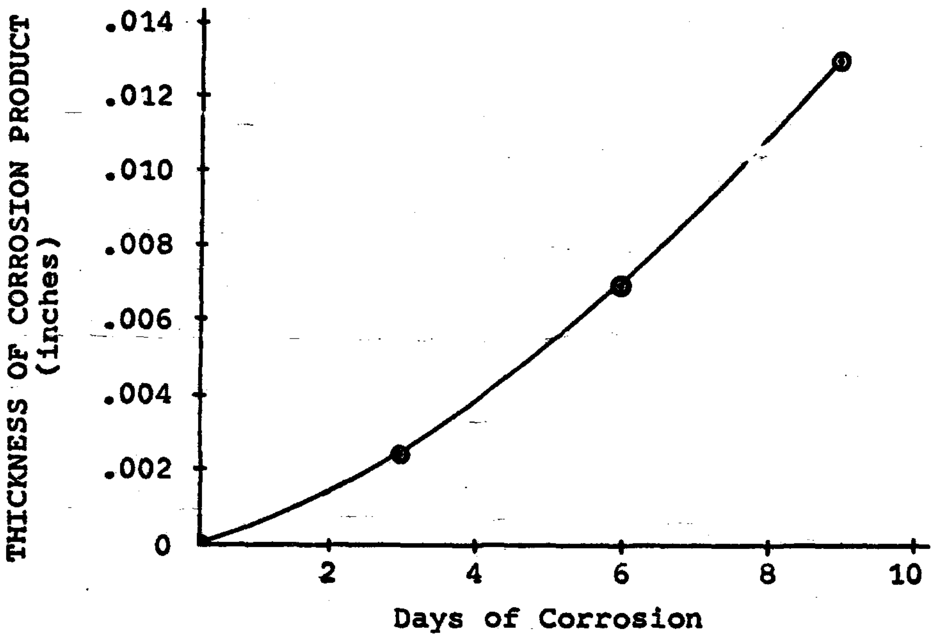

FIGURE 5 - THICKNESS VERSUS DAYS OF CORROSION

TABLE 4 - CORROSION MEASUREMENTS

PLATE NUMBER	LENGTH OF EXPOSURE (DAYS)	CORROSION PRODUCT (INCHES)
1	0	0.0
2	3	0.0025
3	6	0.0070
4	9	0.0130

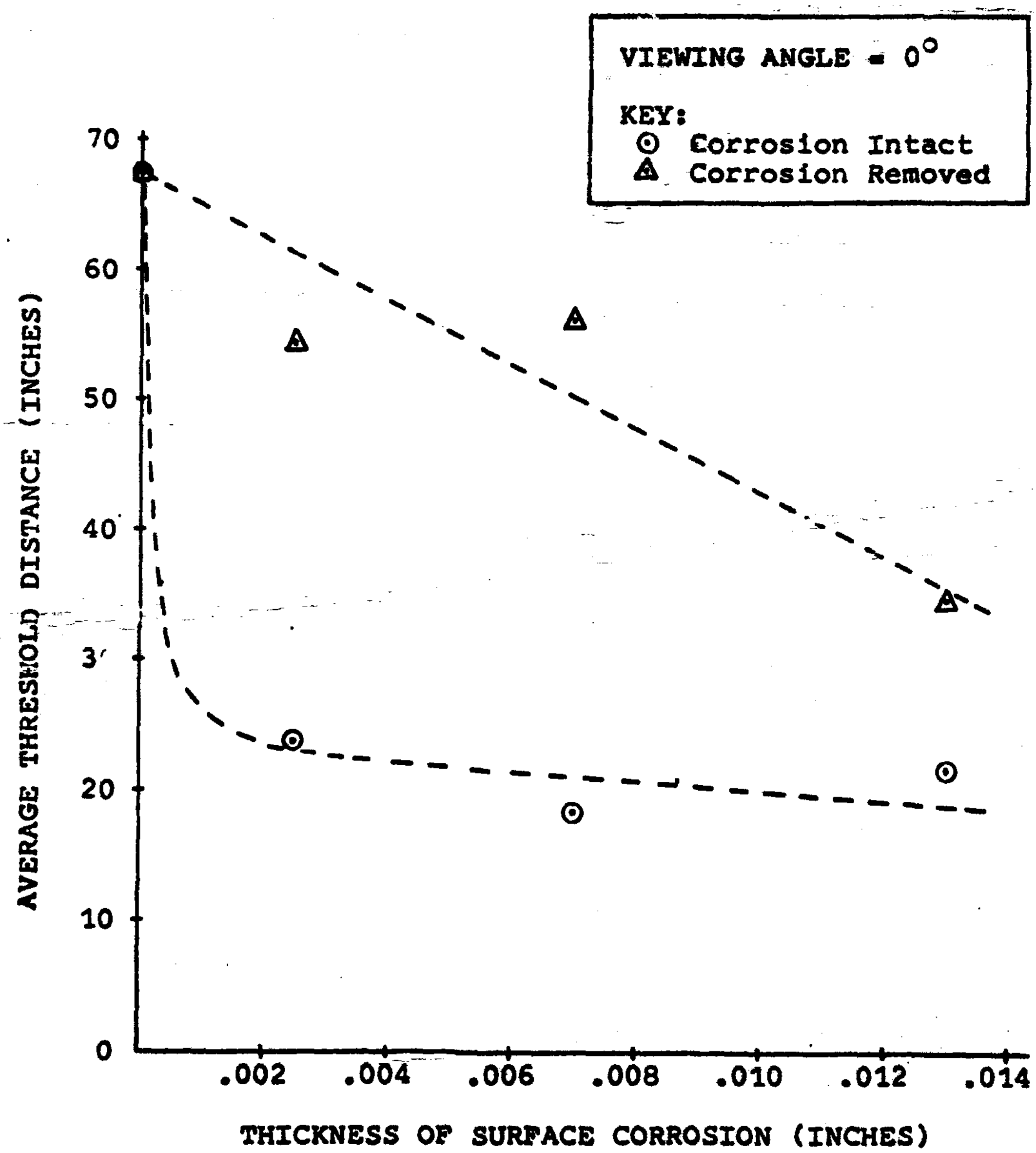

FIGURE 6 - THRESHOLD VERSUS CORROSION THICKNESS 1

the interaction between corrosion level and corrosion removal is not obvious, it can be seen that removing the corrosion has less effect as the degree of corrosion increases.

Figures 7 and 8 further examine the interactions found to be significant in the ANOVA. Like the previous graph, these graphs are both average threshold distance versus thickness of corrosion product. This time, however, corrosion removal is the variable held constant in each graph while a set of points are plotted for both viewing angles. Looking first at the interaction of corrosion level and viewing angle, it is seen that the greater the degree of corrosion the larger the effect of viewing angle. This is true for both graphs.

The next interaction of corrosion removal and viewing angle is not nearly as significant as the previous effect and is, therefore, not as easy to see. It can be seen from the graphs that the thirty degree angle had slightly better recognition qualities when the corrosion product was intact, while when the corrosion product was removed, neither angle showed an advantage over the other. The final interaction, due to its complexity, is not visible in the plots. Further steps will not be taken to identify it because as stated earlier the object of this section of the analysis is primarily qualitative. As a result this

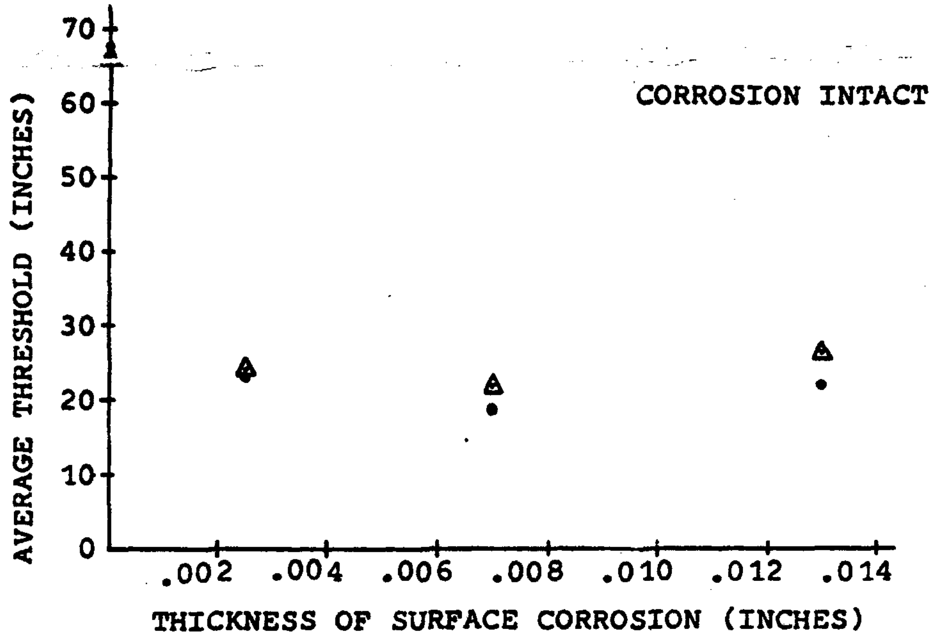

FIGURE 7 - THRESHOLD VERSUS CORROSION THICKNESS 2

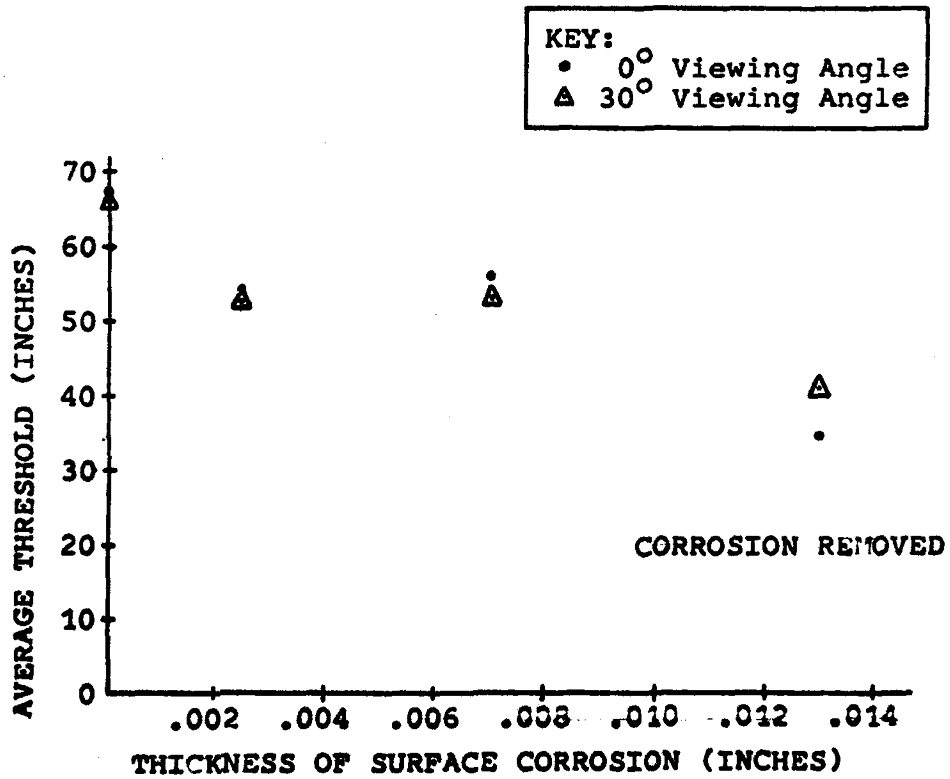

FIGURE 8 - THRESHOLD VERSUS CORROSION THICKNESS 3

three-way interaction does not have a large enough significance to make it of much importance.

The final plot (Figure 9) was constructed to provide a brief visual summary of the differences in recognition capabilities of the ten subjects who performed the experiment. This graph gives a value of subject overall average recognition threshold distance for each of the subjects. This quantity is simply the overall average of all the recognition distances for each subject. As can be seen from the graph, considerable variation exists, as was expected.

This concludes the analysis of the experimental data. Conclusions will be drawn from the analysis in the next chapter.

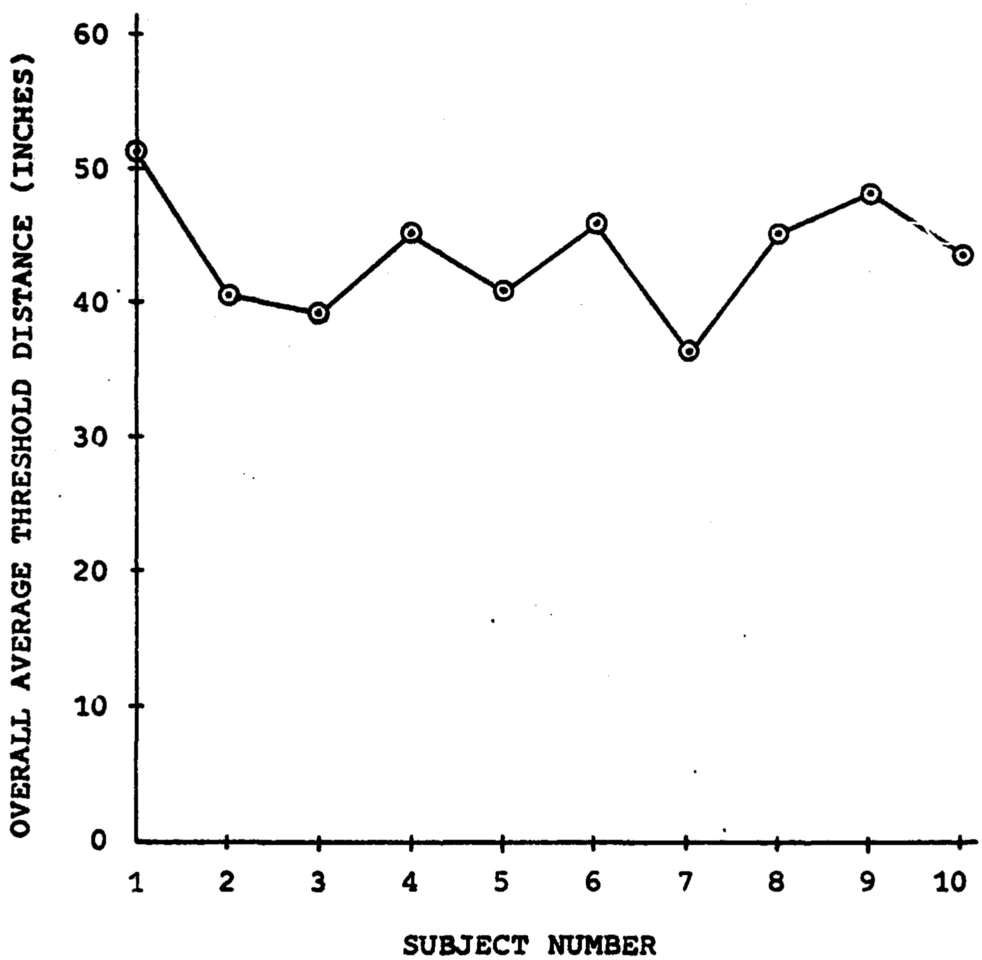

FIGURE 9 - SUBJECT VARIATION

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

The objective of this research was to examine the effects of corrosion upon the recognition of symbols stamped into unprotected steel surfaces. Because of the many parameters influencing this recognition, it was necessary to perform the research holding several parameters at constant values. These values were chosen so as to be representative of conditions found in actual use. As a consequence, the experimental results, while theoretically applying only to the conditions of the experiment, are generally representative of marking recognition. The remainder of this chapter will interpret the experimental results, make recommendations for better markings from the corrosion aspect, and propose extensions of the research presented in this paper.

One of the most significant findings of the experiment is the effect of even a small amount of corrosion upon the recognition of stamped symbols. After only three days in the corrosive environment, the average threshold distance for recognition dropped over sixty percent. The new recognition threshold was well below the twenty-eight inch minimum set by the Military Standards[6]. It is recommended, therefore, that at least the area of the iden-

tification markings be effectively protected against corrosion. This is especially important for components large enough that the positions of identification markings are not evident. In this case, the detrimental effects of corrosion would be even more serious, since in a study by Blackwell[5] it was shown that when the location of a visual target is not known, a significantly higher contrast is required for perception. This situation could also be improved through the use of a consistant system for the location of stamped markings so the technician knows where to look for them.

Another significant conclusion from the experiment is that the removal of corrosion product becomes considerably less effective as the degree of corrosion increases. Thus, while at first most of the recognition degradation due to corrosion can be eliminated by simply removing the corrosion product, the point is soon reached where the recognition characteristics remain severely degraded. This stresses the importance of protecting markings from highly corrosive environments or long periods of exposure to mildly corrosive environments.

The final conclusion to be drawn is that although viewing angle was significant in several interactions, the effect of viewing angle is not large enough to be an important factor in marking placement.

The logical extension of the research presented in this paper would be a study of the methods of protecting steel from corrosion, again using recognition threshold as the dependent variable. Such research, however, could not be justified since the time required to test the large number of protective coatings would be prohibitive. The best method of choosing effective protective measures, therefore, would probably be to refer to existing corrosion research and base decisions upon corrosion prevention properties and economic considerations.

Another large area of experimental research could center around the apparatus developed for the research presented in this paper. The visual apparatus employed to determine recognition threshold distances for the stamped symbols could be easily modified for other visual research. The advantages of the apparatus are: the distance between the viewer and the target is measured continuously, the trials are performed rapidly, a great variety of visual targets coud be used, and many of the biasing factors of human factors research are cancelled out (e.g. reaction time).

APPENDIXES

APPENDIX A

ILLUMINATION TESTING

The size of the incandescent bulb needed to produce the one-hundred footcandle illumination level was determined using a portable light meter, light bulbs of assorted wattages (40, 60, 75, 100), and the viewing enclosure to be used during actual experimentation. The bulbs were placed into the apparatus one at a time and light meter readings taken. If none of the bulbs had produced the desired illumination, a dimmer switch would have been required. As it turned out, however, the sixty-watt bulb produced an illumination of ninety-eight footcandles which is close enough to the desired level.

APPENDIX B

SUBJECT INSTRUCTIONS

THIS APPARATUS IS PART OF A VISUAL EXPERIMENT YOU ARE GOING TO TAKE PART IN. YOU WILL BE OBSERVING METAL PLATES - MARKED SIMILAR TO THIS PIECE OF CARDBOARD - AS THEY ARE MOUNTED INSIDE THIS BOX.

TO AID IN MEASUREMENT YOU WILL BE ASKED TO POSITION YOURSELF SO THAT YOUR FOREHEAD IS JUST TOUCHING THIS BAR. AFTER YOU ARE POSITIONED, THE BOX CONTAINING THE PLATE WILL SLOWLY BE MOVED TOWARDS YOU. AS SOON AS YOU CAN RECOGNIZE AT LEAST THREE OF THE LETTERS YOU WILL SIGNAL WITH THIS CLICKER. IF THE LETTERS CAN NOT BE RECOGNIZED AFTER THE BOX HAS BEEN MOVED ALL THE WAY IN, YOU WILL INDICATE THAT SUCH HAS HAPPENED.

NEXT THE BOX WILL BE MOVED AWAY FROM YOU. WHEN YOU CAN NO LONGER RECOGNIZE THE LETTERS YOU WILL SIGNAL AGAIN AS BEFORE.

THIS PROCEDURE WILL BE REPEATED.

I WILL FIRST PUT THIS SAMPLE INTO THE BOX TO DEMONSTRATE THE TEST PROCEDURE.

ARE THERE ANY QUESTIONS BEFORE WE BEGIN?

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